Three-Dimensional Modeling of the Big Hill Strategic Petroleum Reserve Site, Texas

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New Orleans, Louisiana

Presentation Outline

- Background
- Objectives of the study
- Integrated Data Sources
- Iterative Gravity Modeling
- Results
  - Minimization of residual gravity anomaly
  - Proximity of SPR caverns to salt flanks
- Conclusions

Background

The Big Hill salt dome in southeastern Texas contains 14 solution-mined underground storage caverns used by the U. S. Department of Energy as part of the nation's Strategic Petroleum Reserve.

The site was characterized in ~1980 and the SPR caverns were developed in mid-late 1980s.

Current storage capacity is ~170 millions barrels, with ~90 million barrels of oil in storage.

Project Objectives

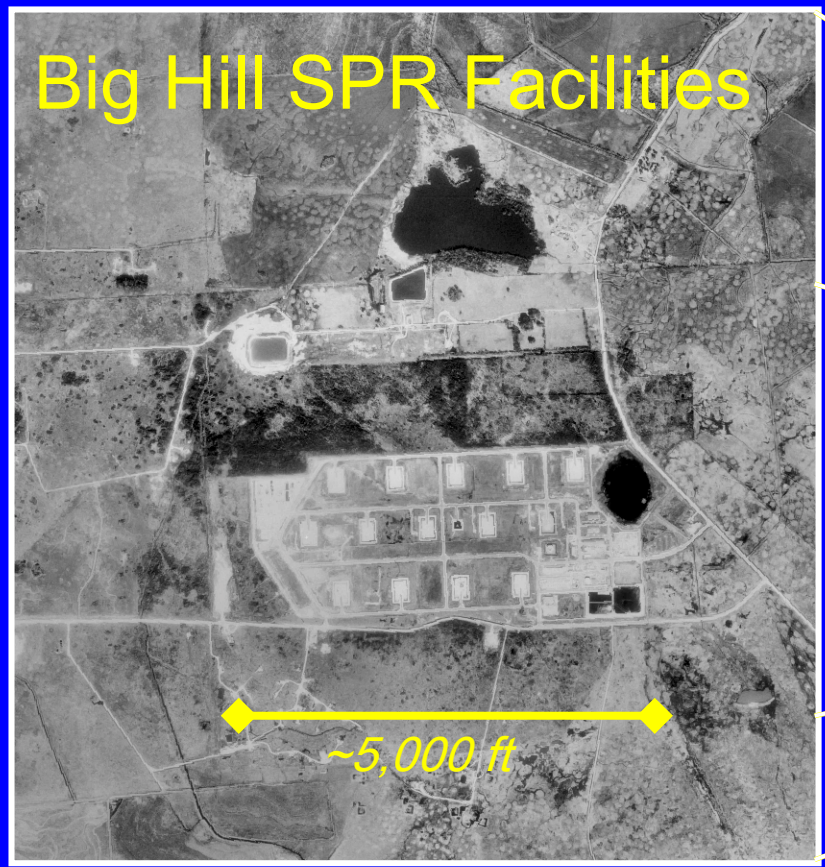
- To demonstrate the utility of state-of-the-art 3-D modeling and visualization techniques
- To produce an updated model of the Big Hill Salt Dome using data newly available since circa-1980

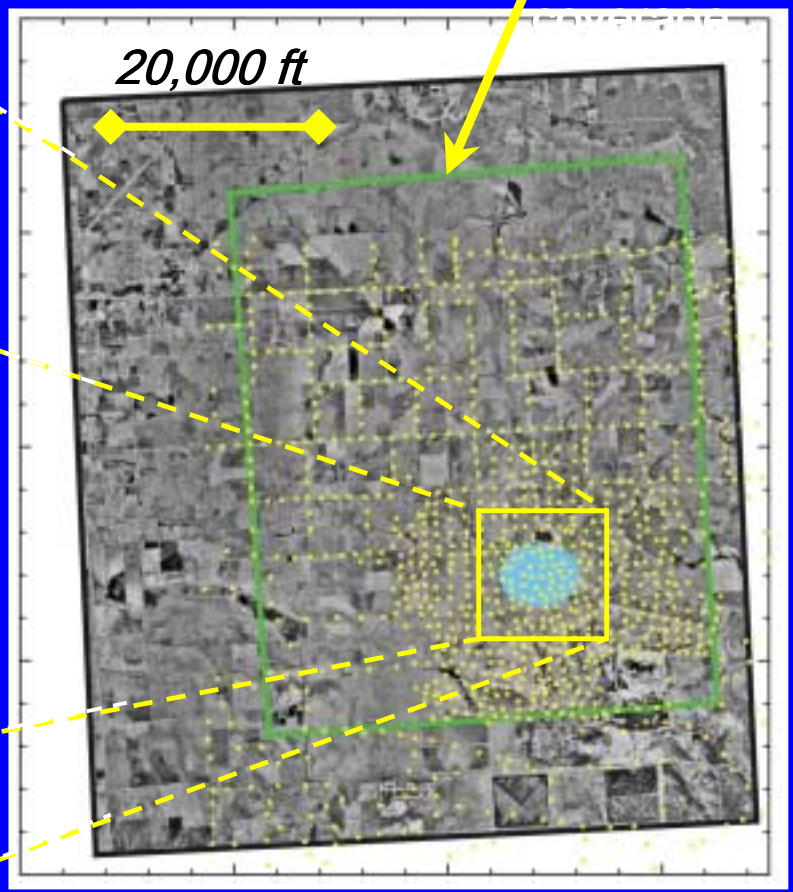
Available **Data**

- ~90 wells with formation tops (dating to 1920's)
- 2-D shallow, high-resolution seismic survey, acquired 1991 for Sandia
- 3-D seismic survey, acquired 1997 by Veritas DGC (60 sq.mi. total; used 9 sq.mi.)
- Extensive gravity measurements, acquired ~1970s-1980s by GETECH, Inc. (800+ stations)
- Down-hole cavern sonar surveys by Sonarwire

Note: data from both Veritas DGC and GETECH, Inc., used by special arrangement under a collaborative partnership with Sandia and Continuum Resources

The Big Hill Site Area with Gravity Coverage

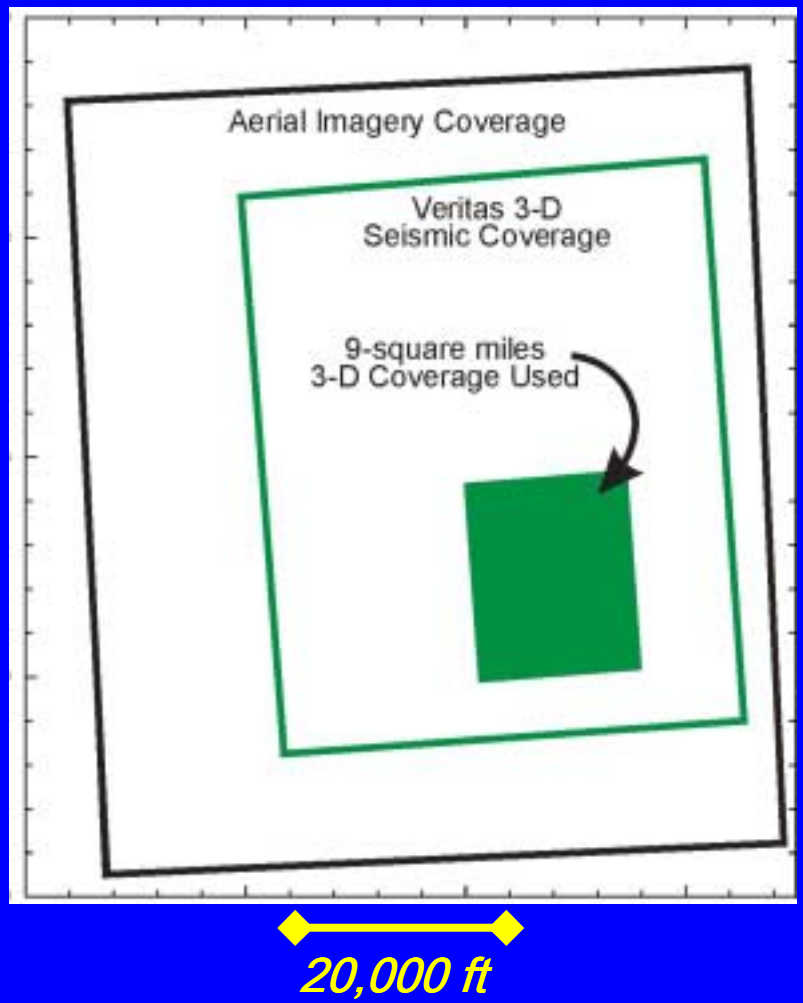




GETECH, Incorporated
Houston, Texas

Sandia National Laboratories

3-D Seismic Survey Coverage



- *Source:*
- *Dynamite*
- *220 ft spacing on 1760 ft lines*
- *Orientation: NE-SW*
- *72 stations per square mile*

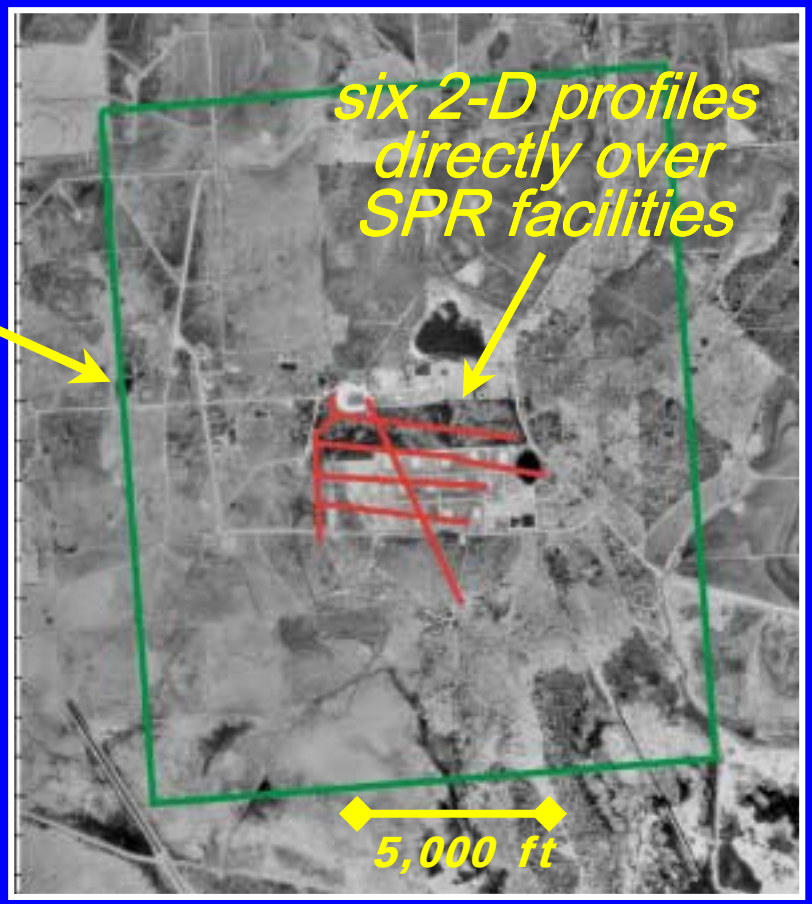
- *Receivers*:
- 220 ft spacing on 1760 ft lines
- Orientation: N-S
- 72 stations per square mile
- Geometry: 8 x 144 channels

Veritas Land Surveys
Houston, Texas

Sandia National Laboratories

2-D Gravity Profiles

9-sq.mi.
3-D seismic
coverage



Source:

- *Airgun (10 cu.in.)*
- *25 ft spacing*

Receivers:

- 25 ft spacing
- Geometry: 3 x 24 channels

Walker Geophysical
Essex, Iowa

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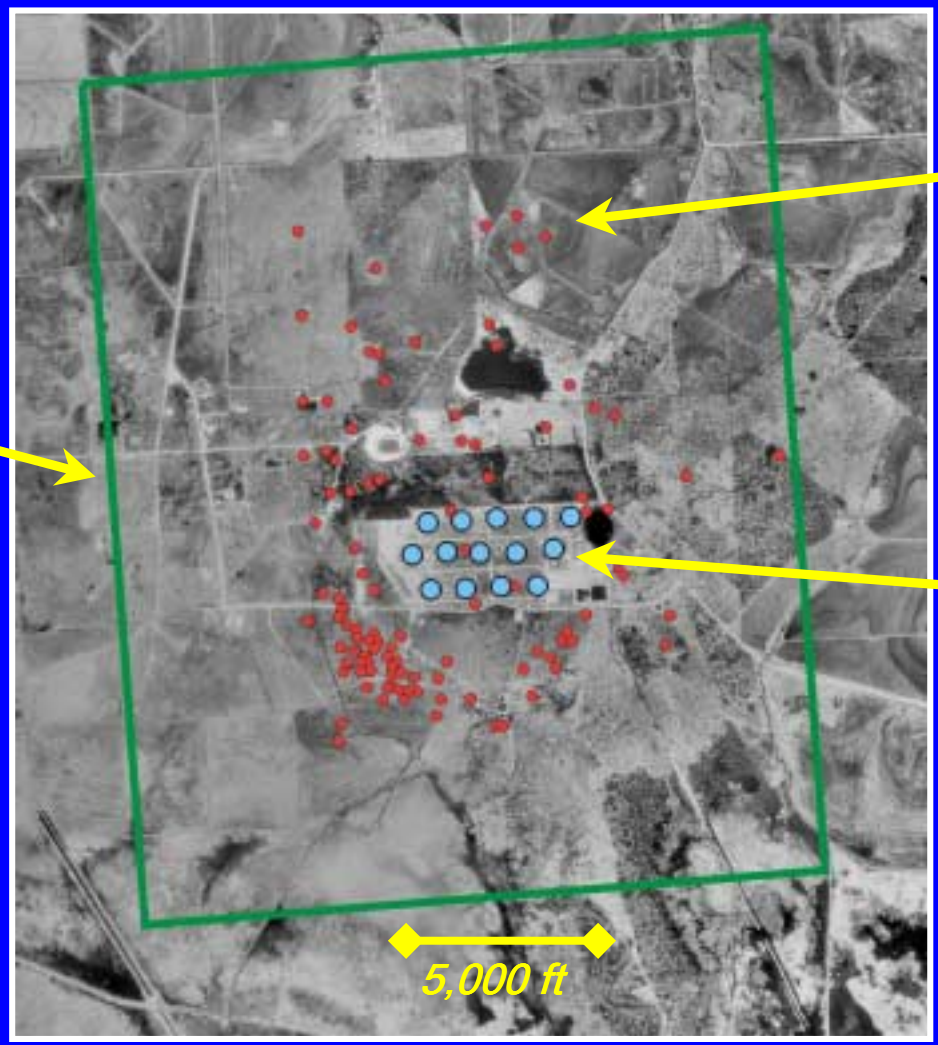
Well Control Database



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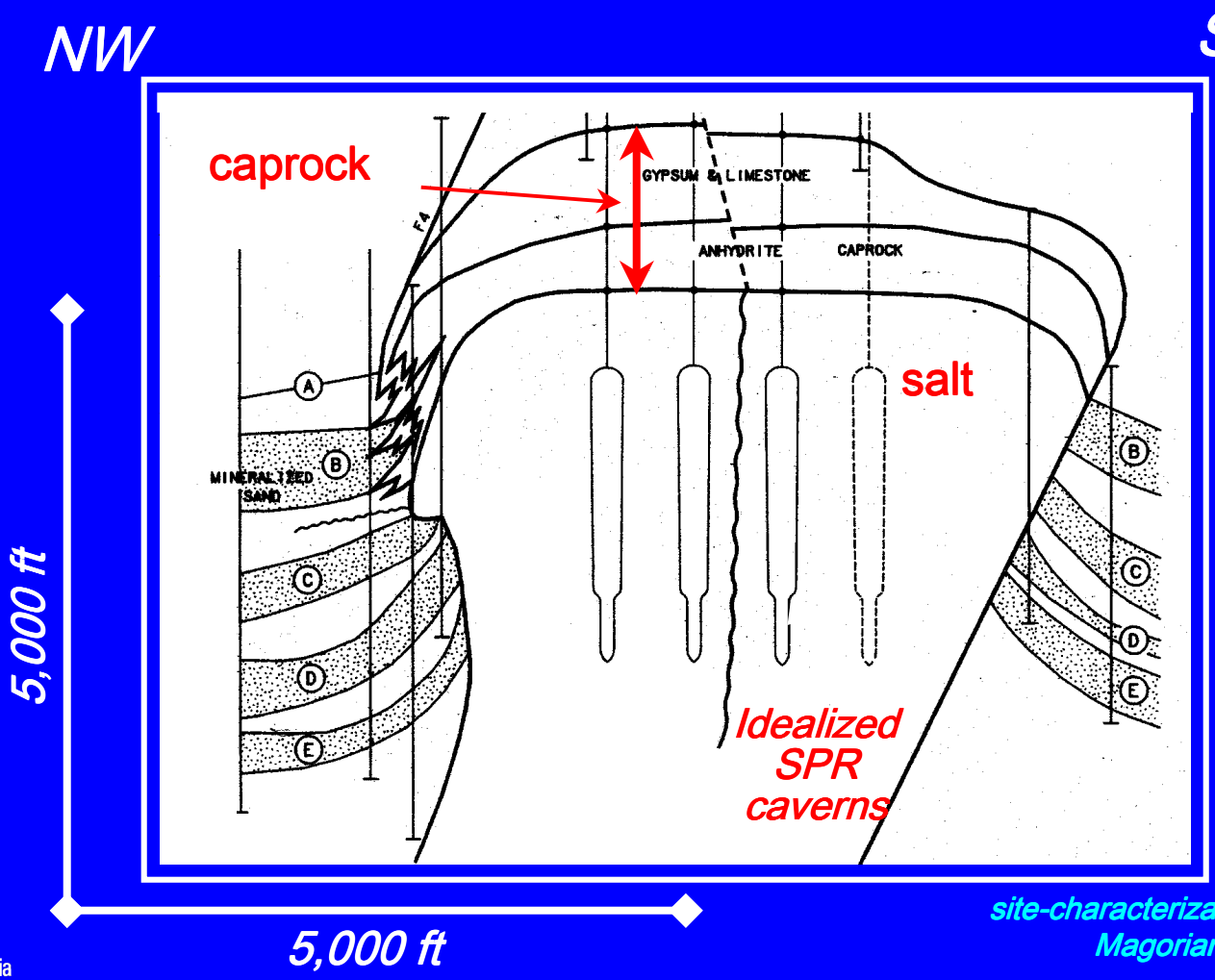
Geologic Cross Section
of the Big Hill Salt Dome



- approximately 1-mile in diameter; roughly circular
- prominent overhang to south
- oil production from upturned Miocene sediments

site-characterization model figure from Magorian & Neal, 1988

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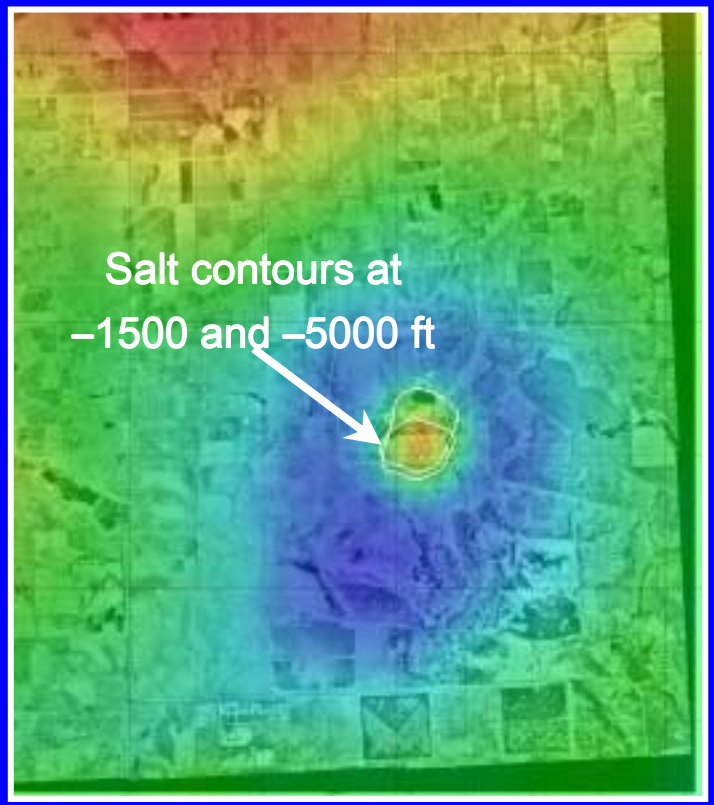
Iterative Gravity Modeling

- Compute standard Bouguer gravity field using field data
- Interpret 3-D seismic to define basic outline of salt dome
- Constrain geometric interpretation with well control
- Interpret caprock geometry with 2-D seismic and well control
- Define 3-D geometric model of salt, caprock, sediments
  - Compute Bouguer gravity model of 3-D geometric model
  - Compute residual gravity anomaly field: $\Delta g = g_{earth} - g_{model}$
  - Adjust geometric model (salt *and* caprock) to reduce residual anomalies
  - Repeat …..
- Insert SPR cavern models and compute proximity indicators

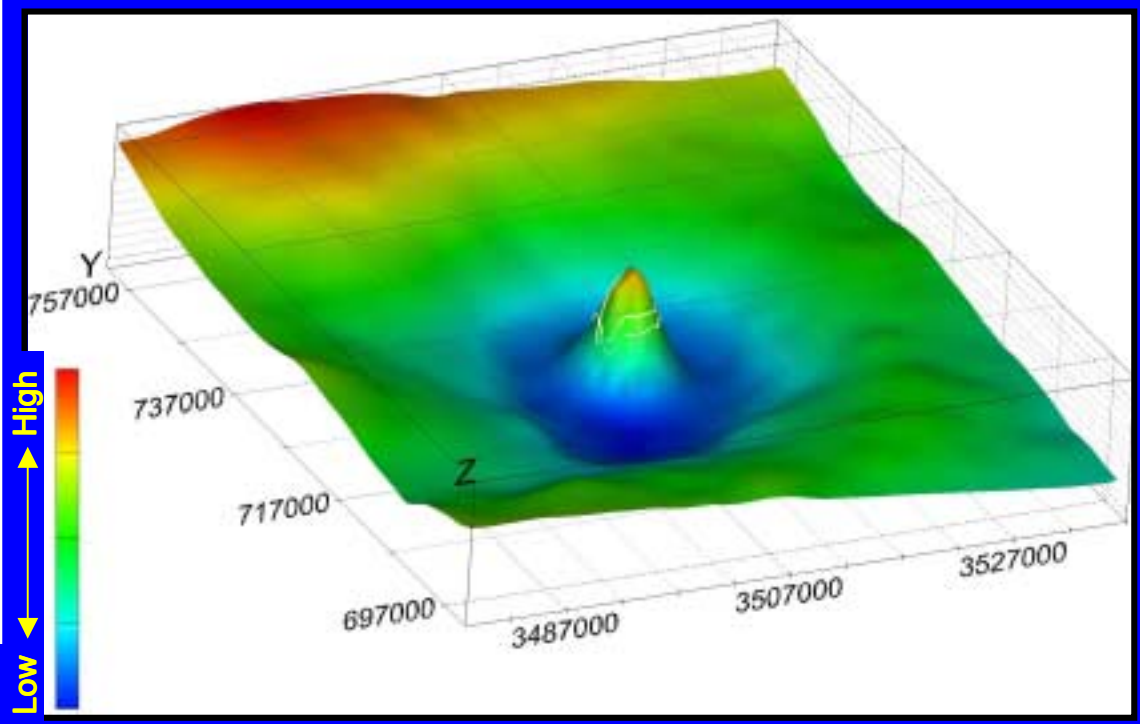
forward gravity modeling uses the methodology of Talwani & Ewing (1960), as implemented in proprietary software by GETECH, Inc.

Bouguer Gravity Response

Target for Iterative Gravity Modeling



Note broad gravity low related to deep-seated salt; sharp gravity high related to shallow dense caprock



gravity scale obscured to preserve proprietary data

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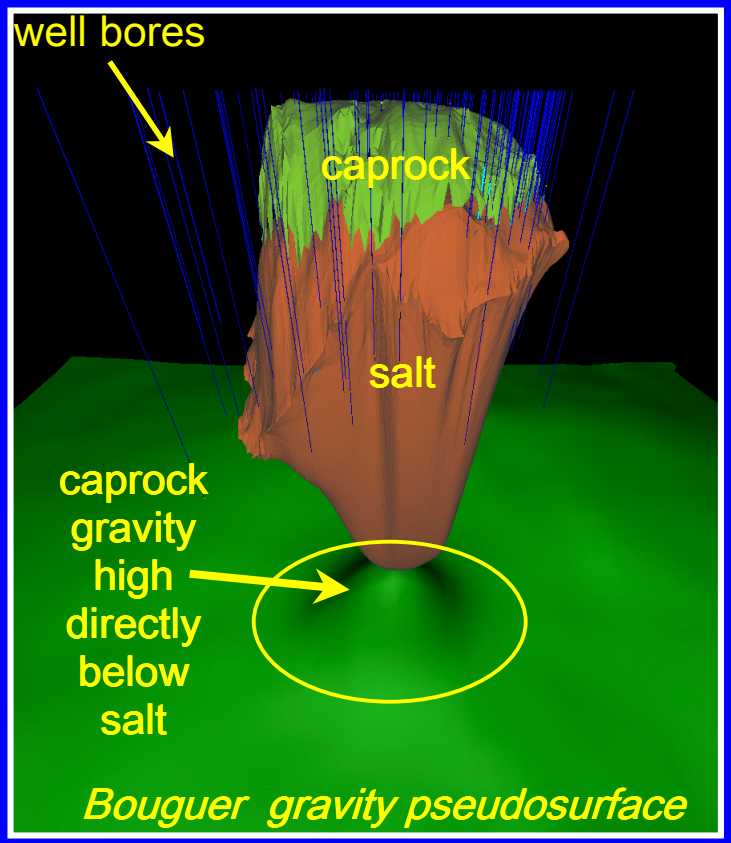
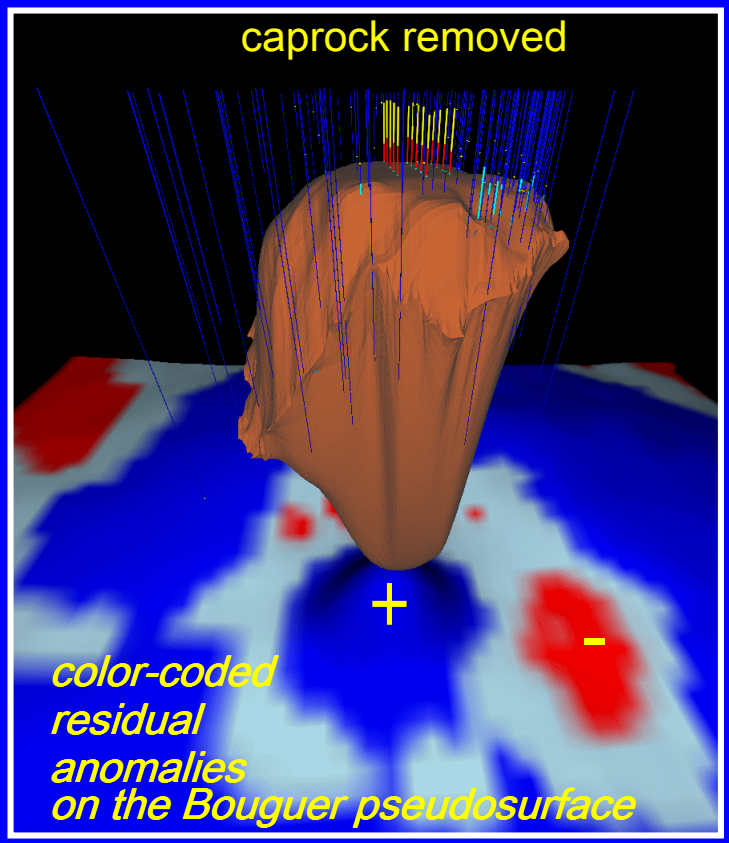
Initial Geometric and Gravity Model





the actual gravity modeling was conducted by Bob Weber of GETECH, Inc.

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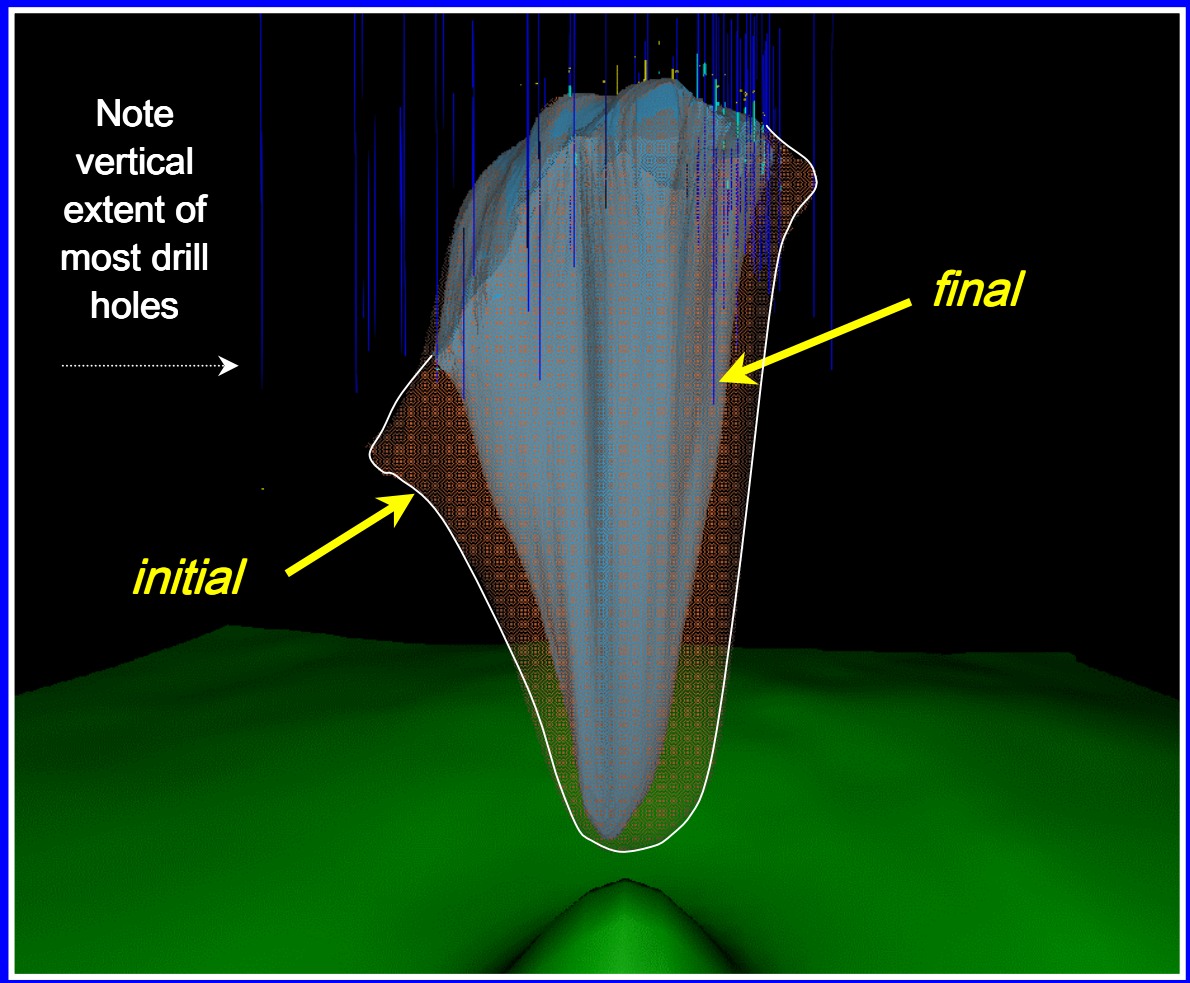
Comparison of Initial and Final Geometric Models



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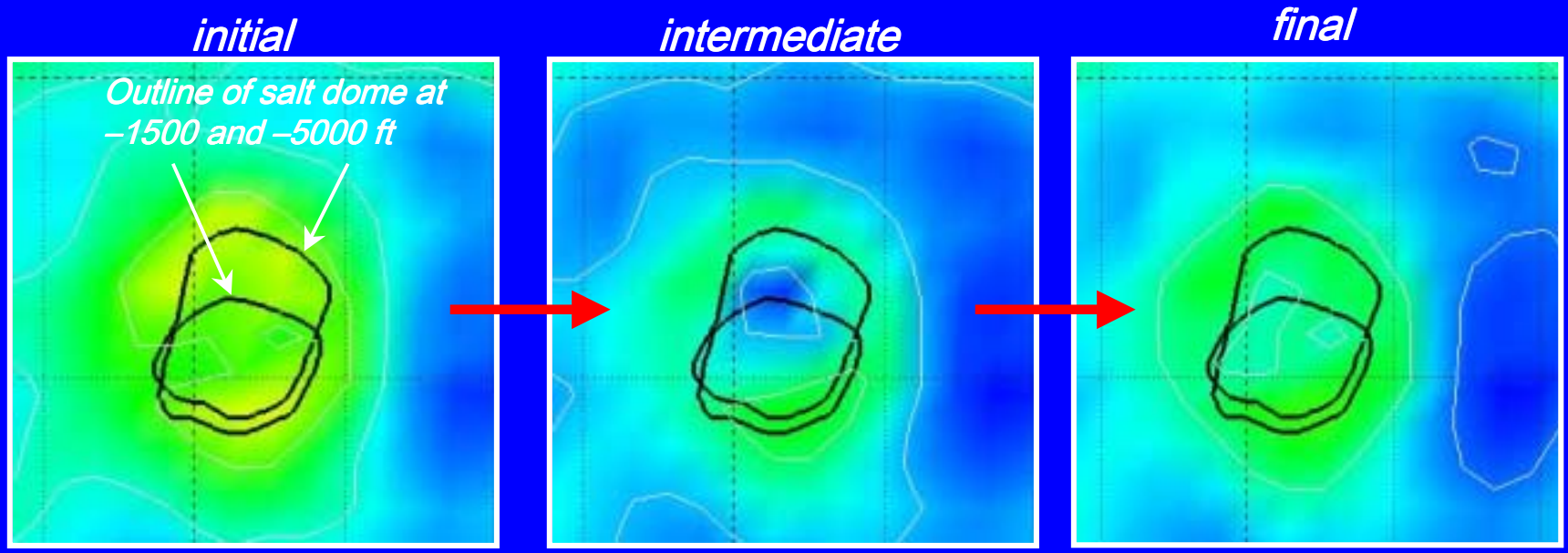
Minimization of Residual Gravity Anomaly Directly Associated with Salt



prominent annular, positive anomaly related to caprock

better salt flank; still too much high-density caprock

bland, near-zero residual closely matches target gravity model

$\Delta g = g_{earth} - g_{model}$ → - + Residual Gravity Anomaly

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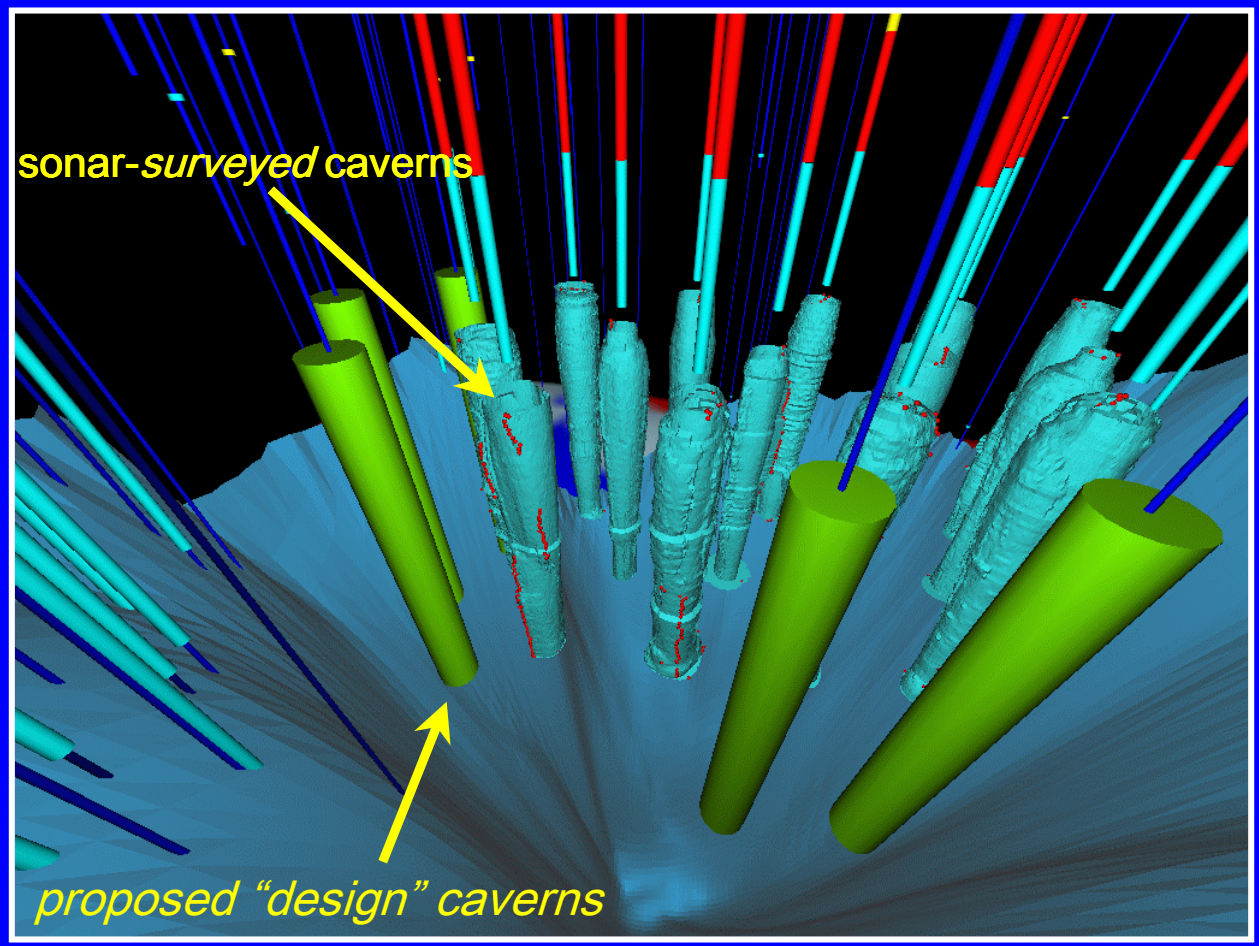
Visualization of SPR Storage Caverns

Sonar surveys indicate modestly complex cavern forms



Red dots on sonar-surveyed caverns indicate points of greatest radius

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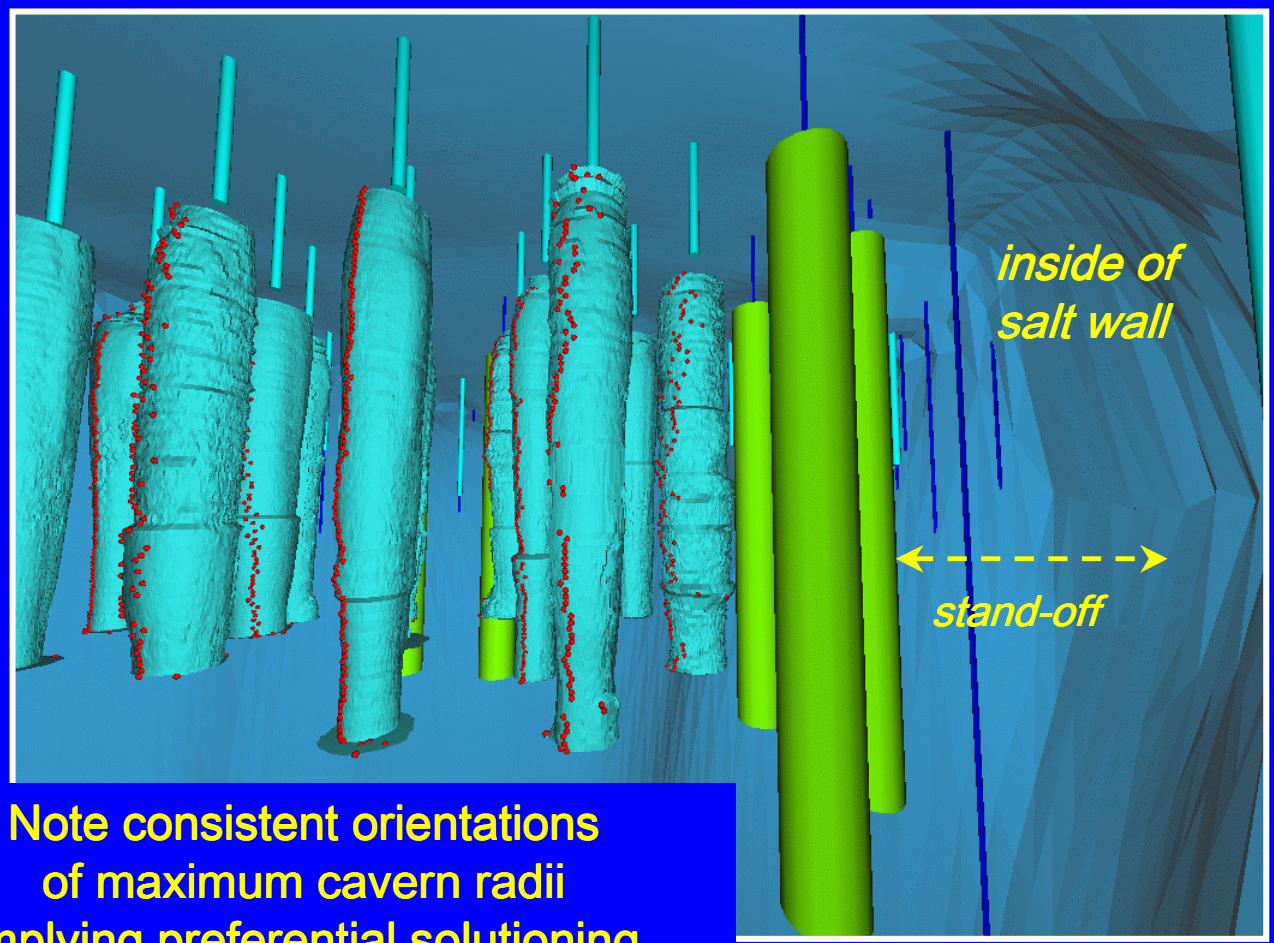
Cavern Locations Relative to Salt Dome Flanks

Red dots on sonar-surveyed caverns indicate points of greatest radius



Note consistent orientations of maximum cavern radii implying preferential solutioning

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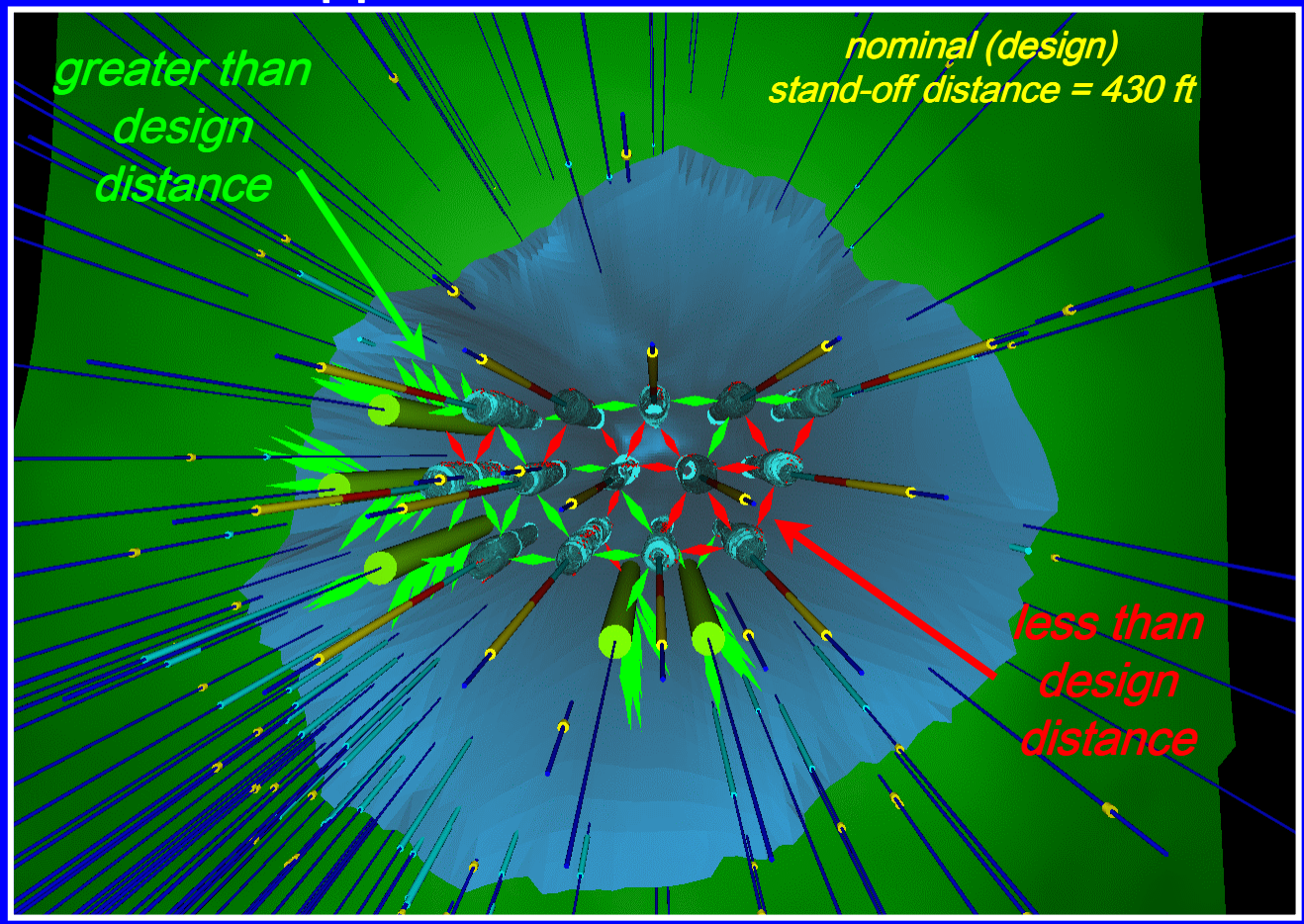
Quantitative Measurement of Closest-Approach Distances

Design cavern stand-off distance based on pillar-to-diameter ratio after 5 fill-and-leach cycles

Design edge-stand-off distance is similar

Closest-Approach 3-D Vectors



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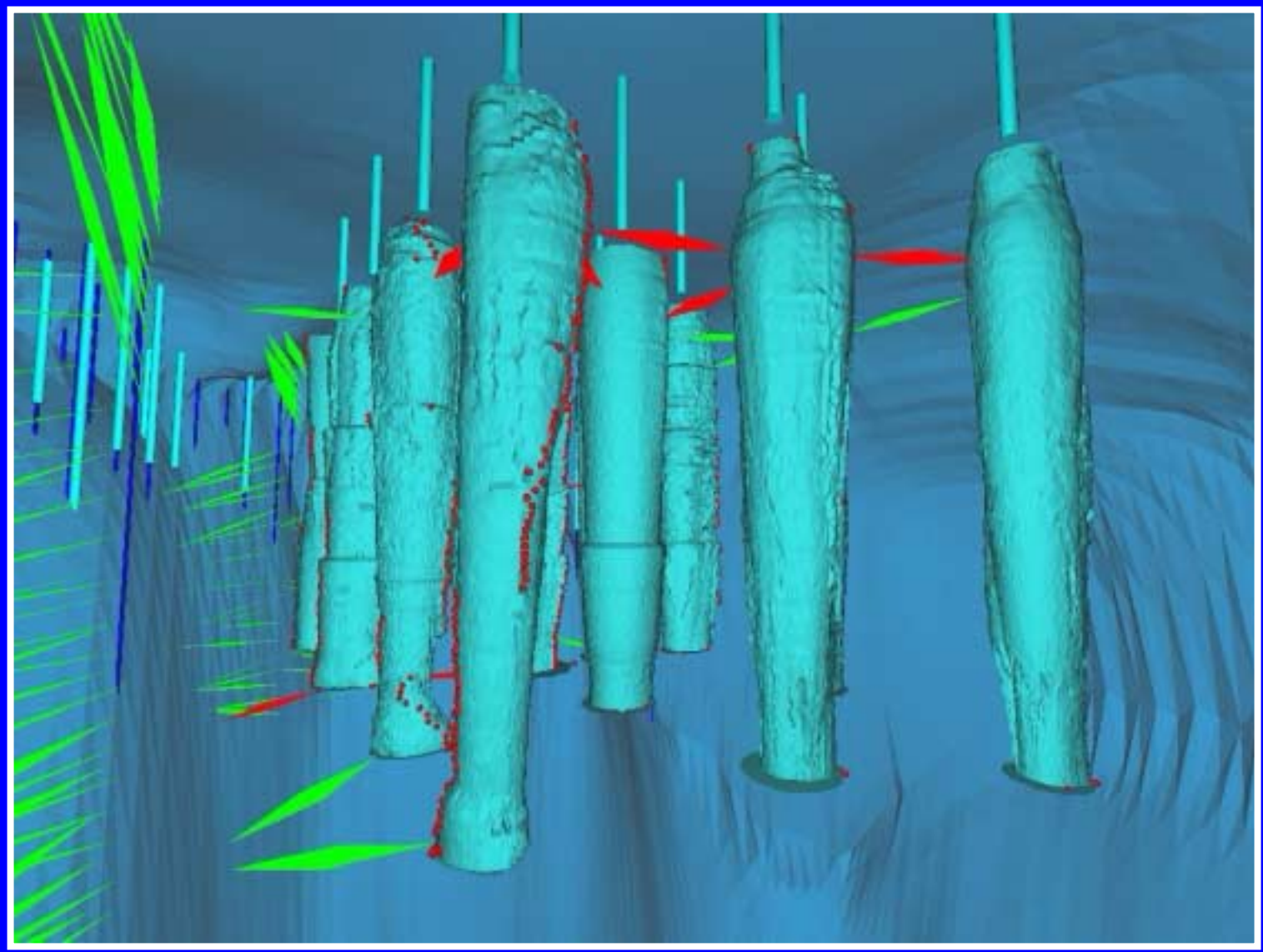
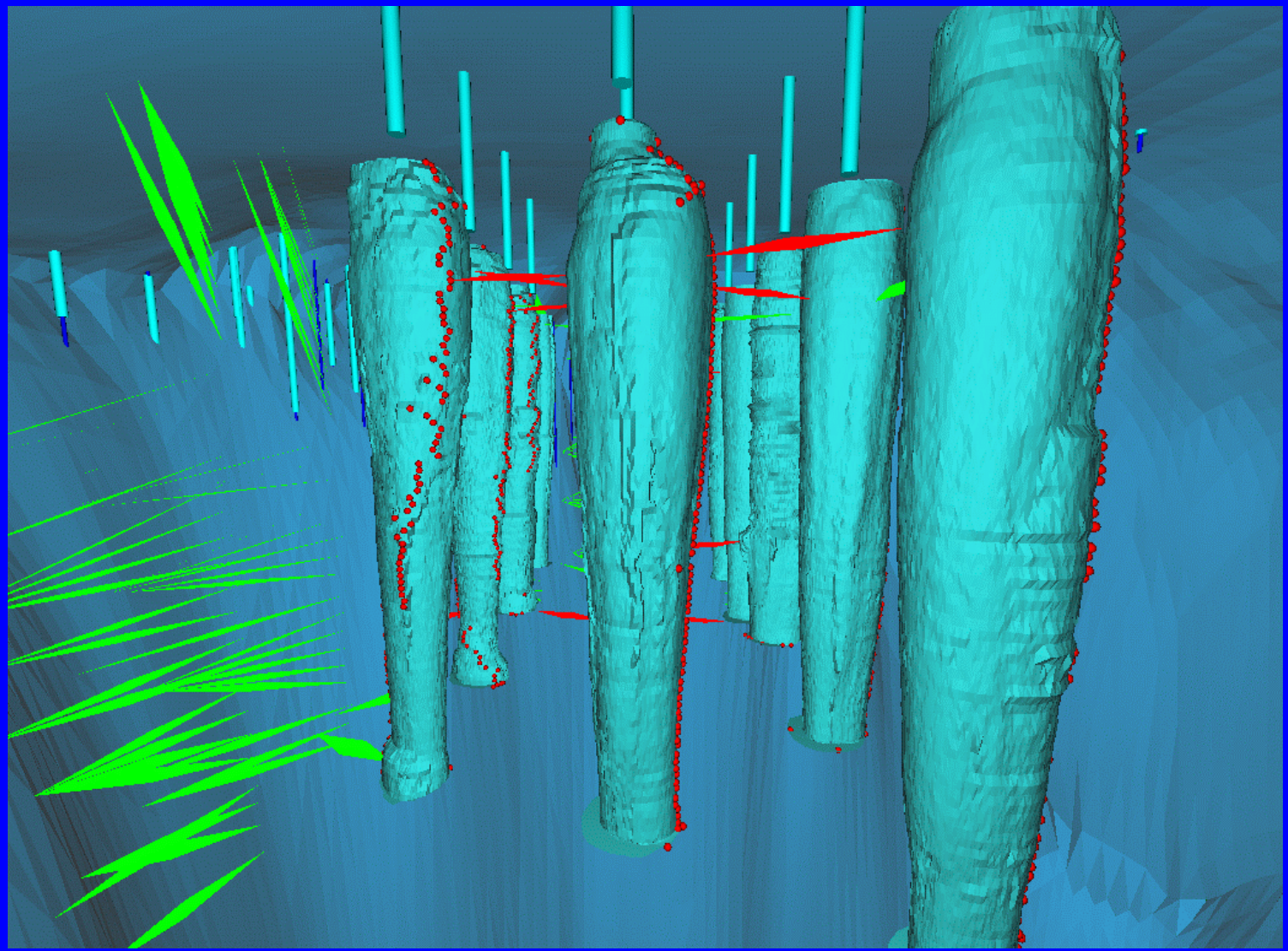
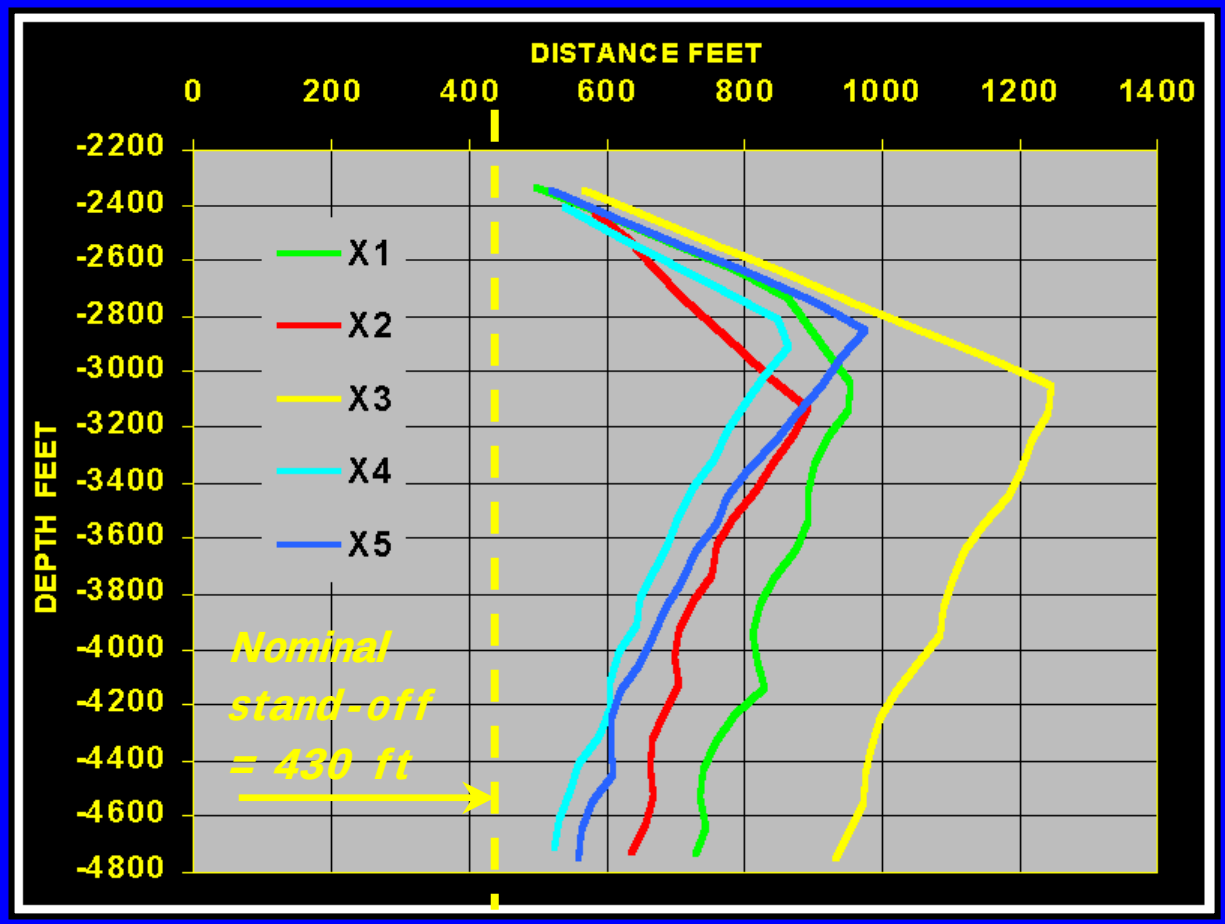
Cavern “Tour” Inside the Dome



Animated “Tour” of the Caverns



Proximity of Potential Expansion Caverns to Salt Flank



Conclusions (1)

- Computer-based 3-D model constructed for the Big Hill salt dome using post-1980 data
- Model constructed using iterative technique to match extensive surface-gravity data base
- Model honors *all* available data (gravity, 2-D and 3-D seismic, well control, down-hole cavern surveys) within limits imposed by professional judgment
- Visualization in 3-D useful for qualitative and conceptual understanding of geology and engineered structures

Conclusions (2)

- Volume of salt allowed by gravity modeling is markedly reduced (~36 percent overall) over that *permitted* by seismic interpretation and well-control data
- There is a preferred orientation of dissolution implied by the maximum diameters of the sonar-measured down-hole cavern images
- Stand-off distances have been measured for both existing and potential SPR caverns; these generally meet design criteria